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TAILORING RISK MANAGEMENT APPROACH FOR THE PRODUCT DEVELOPMENT ENVIRONMENT

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1. Introduction

Positive impact of risk management (RM) activities on product development (PD) outcomes was several times confirmed by various studies and researches [Olechowski et al. 2012]. Nowadays, many R&D organizations perceive the benefits of RM in their engineering systems development projects and businesses, when it is conducted within a mature and effective process and supported by a comprehensive infrastructure [RiskSIG 2002]. However, some organizations still consider it as an overburden and are unaware of the assistance which can be provided by RM [Škec et al. 2012].
Tailoring RM strategy within the product development context according to needs of the specific organization can facilitate the overall RM process. While some organizations identified need for rigorous and very strict organization-wide RM process in all aspects of their businesses, others just require some basic understanding on RM practices which can be used occasionally or on demand. Different project types and associated risks have to be managed in accordance with a given context, since — "one size does not fit all" [Hall and Hulett 2002], [Shenar et al. 2002]. Using risk management maturity (RMM) models proposed in the literature [RiskSig 2002], [Yeo and Ren 2004], it is possible to evaluate and monitor as-is situation of RM in organization, but also set required objectives in terms of RM practice. One of the most important drawbacks of present organization RMM models is its exclusive descriptive and diagnostic character. In order to expand those models and allow their usage for prescriptive purposes in relation to desired maturity level, the paper is describing recommendations for tailoring RM process with accordance to product development context. To accomplish the objective, different RM approaches were assigned to different levels of already established RMM models.
Case study on product development process in company that is providing technology and services for nuclear industry was used for validation of the presented proposal and to illustrate possibility of RMM model extension for improvement of their present RM practices.

2. Research background and related work

2.1 Risks in product development process

Although exact wording of the risk definition may differ, many of those imply PD risk as a possibility that an undesired outcome disrupts your project (e. g. [Smith and Merritt 2004]). Researchers mostly perceive PD risk strictly negative, however certain researchers [Hillson 2002] and standards [PMI 2004], [ISO 2009] comprehend risk as a term that could represent opportunity. For the purpose of this research, risk is perceived as a negative event, or as threat.

According to Browning [2002], the product development risk "stems from uncertainty regarding product performance in the marketplace and the ability of the development process to deliver that product within a given schedule and budget—and the consequences of undesirable outcomes". Hence, the time, cost and performance outcome uncertainty influences the overall project outcome and makes risk a central issue in the management of the PD projects. Risks are encountered in every product development process, emphasizing necessity for RM [Unger and Eppinger 2009].

2.2 Risk management in product development

Since PD process is a chain of activities which starts with understanding of the market opportunity and ends with delivery of the product [Urlich and Eppinger 2003], it is vulnerable to various risks which can emerge during the process. PD process can be perceived as a process of uncertainty reduction and risk management [Gericke 2011]. Therefore, structured and systemized PD process accompanied with usage of appropriate methods and tools reduces uncertainty and risk in general. Many processes and tools for improvement of product development process management were invented such as Lean, Six Sigma, Total Quality Management etc. but there is still considerable amount of uncertainty in the PD process [Kim and Wilemon 2003]. Therefore, standardized and structured PD process cannot address and treat risks sufficiently in all situations.

Often PD is conducted as a project [Pahl and Beitz 2007] and approaches for project management are regularly applied. As defined by Levardy and Browning [2009], "projects are temporary allocations of resources commissioned to achieve a desired result". Again, many different frameworks and tools can be found in the literature helping to manage all types of projects [Kerzner 2004]. To address remaining amount of uncertainties and risks occurring during projects, project management was implemented with the following assumption that consideration of two similar projects both taking place in similar environments and having equal access to the resources but one applying a more structured approach to the project management and other things being equal, it will result in a higher probability of achieving desired project goals than the comparison case. Emphasis in this literature corpus was strictly put on satisfaction of the cost, time and quality (in general) restrictions. However, in recent years significant part of researchers and practitioners believe that many new project criteria and measures have to be incorporated to holistically evaluate and monitor project performance.

Since risks can be defined as "effect of uncertainty on objectives" [ISO 2009], risk management allows us to modify our risk perception and understanding depending on objectives of our project and process performance. Building on this premise, one of possible solutions for embracing different perspectives of the project is formalized RM approach. Although RM is an integral part of the project management, very often it is not used or implemented at all, or at least not on the satisfactory level [Yeo and Ren 2004]. Formal RM approaches mostly differentiate identification, analysis, evaluation, treatment and monitoring of risks [Smith 2002], [ISO 2009]. However, some authors describe RM process with different granularity or including sub-phases such as planning, prioritization etc. [Ferreira et al. 2005], [Raz 2005]. RM starts with risk identification - a process of recognizing risks for which heuristic, analogical and analytical methods can be used [Grubisic et al. 2011]. Within risk analysis, risk probability (or likelihood) and impact (or severity) should be estimated, allowing risk evaluation afterwards. Based on evaluation outcome, appropriate treatment and mitigation strategies will be developed [Gericke 2011].

In this paper, different techniques and methods within these three approaches (PD methodologies, PM methodologies, formal RM) for managing risks are analyzed in order to provide recommendations about which approaches (and techniques within) can be used on different levels of RMM and how to incorporate them in the overall RM approach.

2.3 Risk management maturity concept

Management maturity concepts are used as a basis for the evaluation and positioning of the organization's current management practices [PMI 2004]. Furthermore, models based on maturity concept represent valuable tool for strategic planning providing standardized approach for benchmarking and measurement of organization performance [Yazici 2009].

Management maturity concept was first introduced for the classification of the software organizations into the five levels of sophistication of their engineering and management practices made by Software Engineering Institute (SEI) at Carnegie Mellon University [Humphrey 1987]. They developed CMMI (Capability Maturity Model Integration) model, which is well-known and used for process improvement. Existing CMMI covers three areas of interest – Development, Services and Acquisition. Risk management aspect is also integrated in that model, represented in Project Management process area (contains 22 process areas) at Maturity Level 3.
Concepts of process or capability maturity were translated and applied to various specific perspectives of PD, for its assessment and improvement planning [Yeo and Ren 2004]. One of management perspectives is RM, for which Hillson [1997] firstly introduced RMM model consisting of four maturity levels (Naive, Novice, Normalized, Natural) and usage of four attributes for their evaluation (culture, process, experience and application). Later, new model was proposed by RISKSig [2002] keeping the same structure as the previous one, but extending it with new criteria (Table 1). In 2009, Yeo and Ren introduced RMM model for the application on the Complex Product Systems (CoPS) Projects, introducing five levels (Initial, Repeatable, Managed, Defined, and Optimizing).

Table 1. Example of the risk management maturity levels by RiskSIG [2002]

Attribute	Level 1 (Ad Hoc)	Level 2 (Initial)	Level 3 (Repeatable)	Level 4 (Managed)
Definition	Unaware of the need for management of uncertainties.	Experimenting with risk management through a small number of individuals.	Management of uncertainty built into all organizational processes.	Risk-aware culture with proactive approach to risk management.
Culture	No risk awareness.	Risk management used only on selected projects.	Accepted policy for risk management.	Top-down commitment to risk management, with leadership by example.
Process	No formal process.	No generic formal process.	Generic processes applied to most projects.	Risk-based organizational processes.
Experience	No understanding of risk principles or language.	Limited to individuals who may have had little or no formal training.	In-house core of expertise.	All staff risk aware and capable of using basic risk skills.
Application	No structured application.	Inconsistent application of resources.	Routine and consistent application to all projects.	Risk ideas applied to all activities.

Within the RM context, one of the most important aspects of its maturity is introduction and retention of the RM process in organization. As stated by RISKSig authors [2002]: „Organizations attempting to implement a formal structured approach to RM need to treat the implementation itself as a project, requiring clear objectives and success criteria, proper planning and resourcing, and effective monitoring and control".
Therefore, in order to enable benchmarking between implementation levels of the RM in the companies, researchers tried to define their own RMM model based on their different attributes. One could expect that companies with more mature RM practices will have better RM and overall performance, but it is not necessarily so.
There is no optimum maturity level that would be considered as appropriate for every organization [Wheatley 2007] and for every project. Often, "one of common myths and misconceptions about projects" is that all of them can be managed in a same way using same approaches and tools [Shenar et

al. 2002]. Trade-off between cost invested in the RM process and gained benefit has to be reached (Figure 1) regarding organization's need for RM rigor and level of detail.

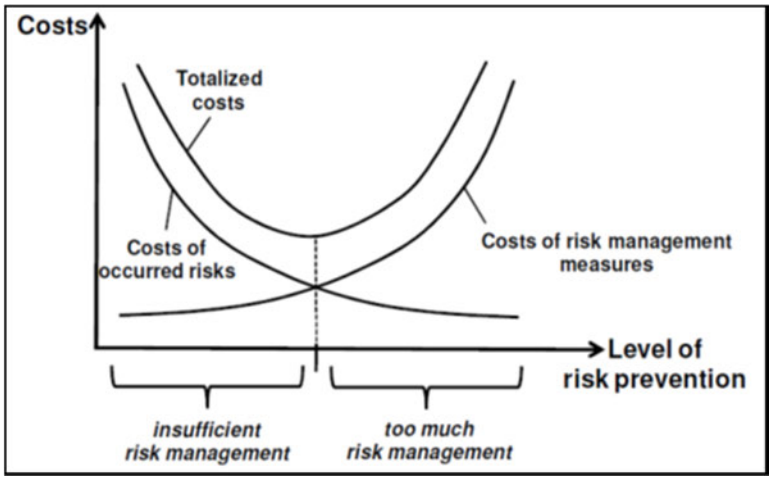

Figure 1. Cost-benefit of risk management ([Ahrendts and Marton 2008], from [Gericke 2011])

Up to this point, research made on RMM levels was mostly focused on characterizing and describing present situation of the RM in the company and on providing stepping-stones indicating what should be achieved next, but without any practical recommendations how to accomplish that. As a consequence, RMM models are typically used reactively for diagnostics, not proactively. Assigning RM approaches (and methods within) to different maturity levels, should lay the groundwork for their comparison and better understanding of RM process in general. Also, as confirmed by Marle and Gidel [2012], first step which has to be made when selecting the right method, or a more general – approach, is to screen them out due to insufficient level of organization RMM. Providing recommendations about which RM methods or approaches should be used will enhance the process of achieving the desired maturity level.

2.4 Risk management methods and their selection

Unfamiliarity with research contributions in RM field and inadequate context recognition for usage of those contributions implies necessity for formulation of recommendations with respect to method application. As stated by Dikmen [2004], there is lack of decision support technique which can provide guidance for RM method selection at different stages of the product development process.

Only a few authors tackled the issue of systematization and classification of RM methods in order to create a normative model and to suggest how to carry out different phases of RM process. Within the field of construction environment (to more precise - BOT projects), Dey and Ogunlana [2004] made an overview of applied methods and tools. Forbes et al. in [2010] presented approach for RM techniques selection, analyzing number of case studies, but again narrowly focusing on built environment context.

Embracing more generic project perspective, multi-criteria decision-making model for selection of project RM techniques was made by Marle and Gidel [2012]. Using this structured approach, group decision-making is facilitated for the purpose of choosing adequate risk identification and risk analysis methods. However, fuzzy set theory, which represents a basis of this approach, seems to be too cumbersome and, due to specific knowledge required for RM method selection, too demanding.

Several contributors were proposing RM selection methods to make it more suitable for the product development context. Each of them was focusing on limited number of criteria, creating matrices which can be easily used by project or portfolio managers. For tackling selection of risk identification methods in product development projects, Grubisic et al. [2011] grounded their approach on criteria such as product design and project management maturity levels, product innovation degree and project team. Recommendations about utilization of certain risk analysis methods were provided by Škec et al. [2013], depending on the project and organization RM characteristics. For the final phase of RM, risk treatment, Gericke [2011] presented categorization of risk treatment strategies and question-based

support for their selection and revision. Due to specific settings of the product development context, RM selection methods, which are specifically developed for the usage in PD and incorporate characteristics of the underlying context, have advantages in comparison to more general ones. Still, these various selection methods are separated and their aggregation would facilitate tailoring formal RM approach within the product development, what is done in next section.

3. Approaches for risk management in PD depending on their maturity level

Product development, project management and formal risk management approaches introduced in previous sections can be also understood as different levels of RM or more precisely as different levels of influence on risks (figure 2). Depending on organizations' needs and preferences, organization can apply implicit (PD management and general project management) or more explicit (formal risk management) way of dealing with emergent risks. All these approaches have to be encompassed in order to provide overall framework for risk management within PD context. As it is presented on Figure 2, first there is necessity to select broader approach (such as PD, PM or RM), and then within each approach to select appropriate method or tool.

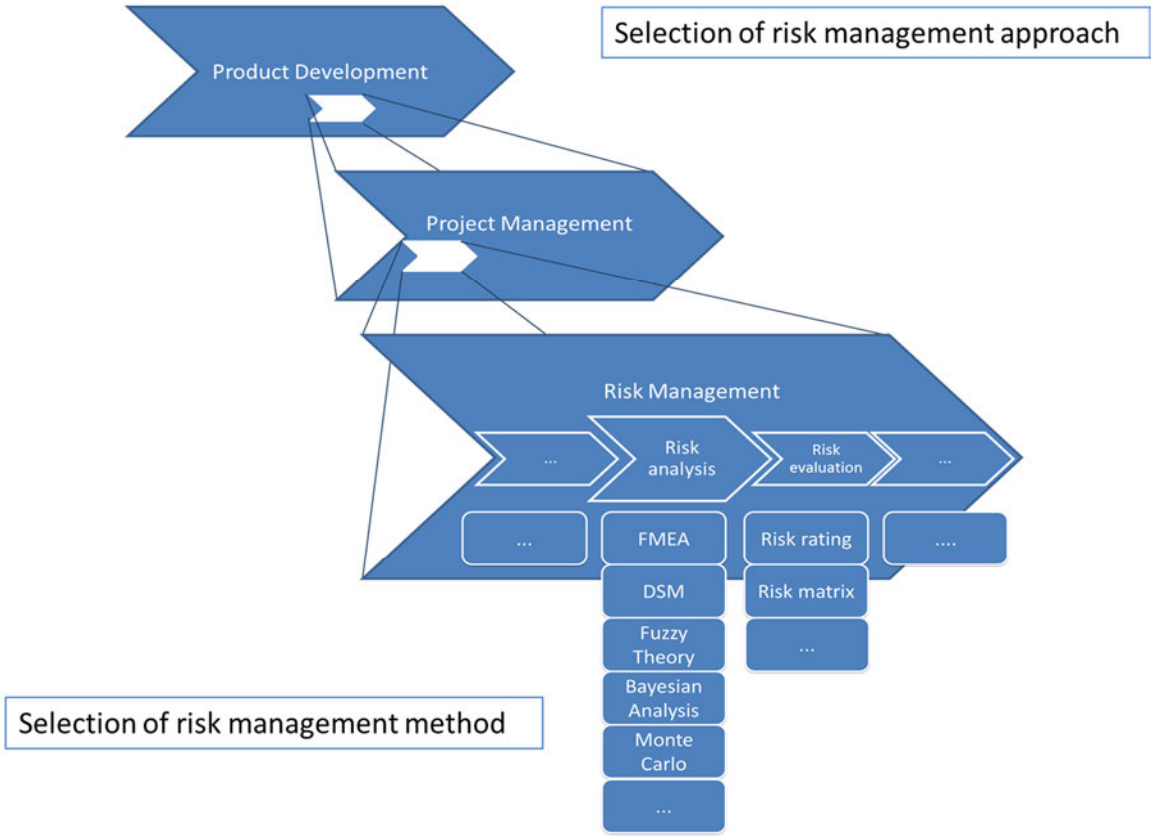

Figure 2. Relations between different levels of managing risks

Using risk management maturity concept as criterion, above-mentioned approaches are assigned to different RMM levels in order to recommend which one should be used on certain level (of course, to define RMM level you have to assess and evaluate various RMM sub-criteria– such as RM application, culture, process, experience).

For the purpose of this research, the RMM model developed by RISKSig [2002] was slightly modified regarding RM phases within particular level (e.g. there is no differentiation between quantitative and qualitative risk analysis) (see Figure 3). Emphasis, in this paper, is put on "process" perspective, although other attributes are interlinked and therefore they cannot be neglected.

Mapping of approaches (PD, PM, RM), and methods within, on different RMM levels extends existing model from the RM process perspective. Until now, only recommendations about generic RM phases on certain RMM level were included in RMM model, without any prescription how to execute them.

Linking methods and approaches to RMM level, provides more tangible output in terms of providing guidance on their selection. Therefore, according to the level of maturity and sophistication of RM in certain company, the RM process will vary – but also methods which should be used differ. Methods can be selected for different phases of the RM process, enabling modification of the whole RM process.
Identification of the present RMM level (measured according to criteria from Table 1) and definition of the desired RMM has to be made first - according to the organization strategy. Based on decision about desired level, first broader approach has to be selected and, then, methods within.
In the next two sections, methods and tools, which are proposed to be used within different approaches for coping with uncertainties and risks, will be enumerated and briefly described. For the initial level of RMM, there is no formal risk management process, but exclusively product development and project management approaches. For higher levels of RMM, research contributions, which focus on tailoring of formal risk management process within the PD context, were collected. Different recommendations for the selection of RM methods will be combined to address whole RM process and provide practical approach for adaptation or adjustment of RM process.

3.1 Level 1 - Systemized product development and project management

On the first level (Ad Hoc) of the RMM model there is no structured RM process or practices. Within companies on this level of RMM, there is no awareness of needs and benefits of RM. Therefore, no one is responsible for collecting and analyzing any type of data and information relevant for RM process. This type of RM is also called "reactive risk management", or crisis management, with no proactive risk identification or planning.
Therefore, on this RMM level, for the purpose of mitigating uncertainties and risks within engineering systems development project, various design methodologies can be utilized. Using those methodologies, PD process will become structured, enabling planning and budgeting (scheduling) of the project. Design methodologies can be used for streamlining of the process, but also for reduction of undesired effects of various types of technical uncertainties. Based on existing design methodologies, various design process models and their representations emerged and proliferated.
Among others, sequential and recursive product development process models stand out as one of the most important and present in literature. Recursive development process can be described as cross-iteration process with flexible reviews, while sequential development process allows narrow iterations and requires rigid reviews [Unger and Eppinger 2010]. Depending on the risk categories encountered during the PD, process types can be selected to appropriately mitigate their negative impact (e.g. technical risks with strict project reviews - sequential, market risks with flexible reviews - recursive).
In addition, as stated by Thamhain [2013], there are various contemporary tools such as rapid prototyping, early testing, design-build simulation, computer aided design/computer aided engineering/computer aided manufacturing (CAD/CAE/CAM), voice of the customer, agile, lean concepts and Scrum etc. which have been credited for reducing project uncertainties, and accordingly project risks (easily can be recognized which of them are exclusively usable just for technical risks).
In an equivalent way, project management methods and tools can be used for management of product development projects. For example, project dashboards, action plans, work breakdown structures and Gantt charts, will create conditions for transparent and agile project organization and increase readiness and awareness of the possible contingencies in the given context.
All of these above-mentioned techniques and methods can be used for the first level of RMM. Very often organizations do not have enough resources or there is no need for higher levels of RMM. If performed adequately, structured and systematic PD and PM process can help to address huge amount of risks indirectly on the first level. Very important aspect which shouldn't be forgotten is maturity of PD and PM, but focus in this paper is put on maturity of RM. Building on this premise, this first RMM level was not further dissolved and segmented according to PMM and PDM models to keep the whole picture clear. Also, valid assumption is that RM is introduced in companies only on higher levels of PMM and PDM, since it is perceived as add-on on existing PD and PM infrastructure.

3.2 Levels 2, 3, 4 – Modifications of RM process

In chosen RMM model, there are 3 more levels (Initial, Repeatable and Managed), each indicating more proficient and sophisticated level of coping with known and predictable risks in comparison to the previous one. On the Figure 3, it is possible to perceive which phases of RM process are included on certain levels of RMM.

On Level 2 (*Initial*) usually there exists some kind of informal RM, characterized only with risk identification and treatment sessions. Risk management methods are used exclusively for limited number of selected projects and their implementation is not organization-wide.

On Third Level (*Repeatable*) of RMM model, besides risk identification and treatment, process also includes qualitative risk analysis. At this level, formal RM process is implemented into their routine organization business processes.

Finally, the most advanced level of RMM model is Fourth level or *Managed*. Both qualitative and quantitative risk analysis methods are used with great emphasis on development and usage of historical databases. Very important part of process is risk monitoring pointing out risk-aware culture with proactive approach. On this level of sophistication, state-of-the-art tools and methods are used with regular evaluation and refinement of existing process.

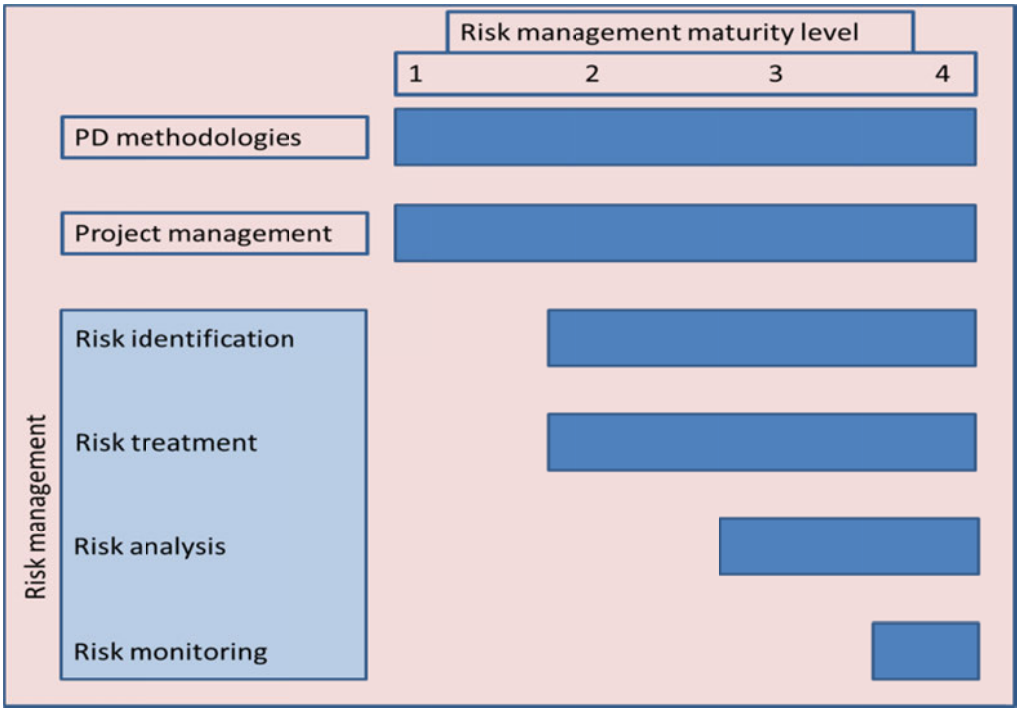

Figure 3. Approaches used on different RMM levels

3.3 Tailoring formal RM for PD context

For each of these individual RM phases (Figure 3) used on particular maturity levels, various methods and tools are proposed for the usage within the product development context. Some of those methods were specifically developed for certain parts and perspectives of the product development, but most of them are taken from other disciplines and modified to become suitable for PD context.

Comprehensive product development context hinders the possibility to easily transfer methods for usage in RM. Few earlier mentioned authors tried to systemize the different RM methods in order to form a normative model and to propose a recommendation on how to carry out different phases of RM process using certain methods. However, their models were strictly focused on one specific phase of RM, ignoring the others (Figure 4).

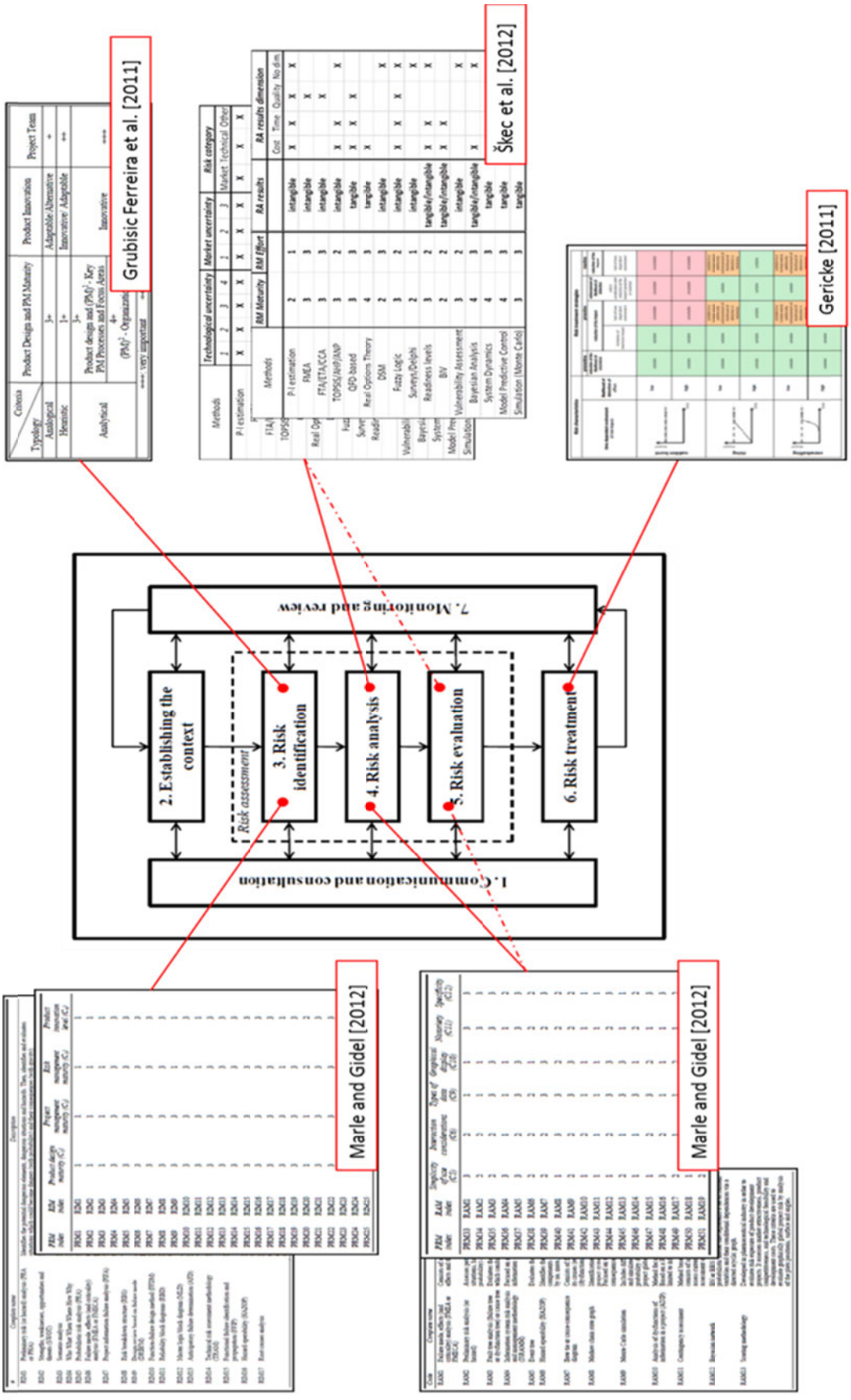

Figure 4. ISO Risk management process [2009] with assigned selection supports

Assigning selection methods and models to specific phases of the formal RM process in product development context enables formation of applicable and practical RM framework. On Figure 4, selection methods are linked to different RM process phases.
Using this embracive approach, each particular phase of RM process (identification, analysis & evaluation, treatment) can be modified according to the internal context of that project and organization. Mentioned selection methods are using maturity as one of the main criteria for deciding on recommended method. Based on required level of risk management maturity in the company, using these recommendations, methods can be selected which are more appropriate for certain environment. For example, for the risk analysis phase, advanced techniques like Monte Carlo simulation won't be used, if there is no sufficient historical risk data which are necessary for proper analysis.
On the right side of the picture, recommendations made specifically for PD context were combined. Selection methods were using matrix form and keeping the same set of criteria disregarding the necessity and possibility to change and modify existing criteria.
On the left side, proposed selection process is more formal and strictly framed by decision-making support, but providing more flexibility in definition of criteria. It results in longer process of tailoring and requires more effort, but can provide more user-specific approach. Although it is not developed exclusively for PD environment (but for project in general), its application and utilization is suggested. Using these recommendations, it is expected to improve overall RM process selecting appropriate methods, especially for RMM level 2, 3 and 4. Also, it can stimulate usage of RM methods implying existence of different methods and tools for the purpose of RM.

4. Case study

Objective of the case study was to analyse used PD, PM and RM approaches in industrial environment and to examine applicability of the proposed approach for selection of RM approaches in PD context. Firstly, to analyse current sophistication level of coping with risks we used already established maturity model developed by RiskSIG [2002]. This model is designed to quickly identify drawbacks and shortcomings of actual RM practice, but simplified enough not to become too tedious or invasive. Analysis of risk management maturity was based on criteria (such as RM application, culture, process, experience) which indicate level of RMM in selected company.
To obtain feedback, we used series of interviews with employees (mechanical engineers and project managers) to identify organization context. This technique provided possibility to modify and extend initial set of RMM questions, but also to direct conversation in a required way and to deepen understanding of encountered RM practices and habits (using follow-up questions). Afterwards, proposed approach was presented and participants were asked to comment on possible usage of the approach and its limitations. In the next subsections, results of our preliminary study will be reported and explained.

4.1 Company PD context

Company, which was selected for our case study, is SME. Their main preoccupation is development of technologies and services for nuclear industry, primary for the power plants examination, repair and inspection. Their activities include research, design, manufacturing and usage of equipment and tools (including software and instruments for non-destructive examination). This organization was selected since they already had experience in risk management and accordingly their feedback was more useful in this preliminary step of our validation. However, as it will be shown in this description, RM is more used in technical aspect of PD process, than for embracing organization and project-wide perspective.
In order to describe internal company context, there is necessity to examine currently implemented project management and product development processes. They use classical project management methods for project budgeting and scheduling such as Gantt charts. From technical perspective, they have formalized product development process with huge amount of procedures which have to be fulfilled in order to enable passing of the critical points during the project. Furthermore, clear distinction is made between procedures for software and hardware development each emphasizing its own specificities.

Their sequential product development process is characterised by very strict project reviews in order to identify and clarify all possible issues. Project review meetings are held on weekly or monthly basis (depending on the project type and urgency of delivery) and have elements of RM process. During the project meetings, participants are several department representatives with different backgrounds (electrical, mechanical, computer science etc.) who discuss interaction issues between different domains and between different parts and assemblies within the systems being developed. Of course, project perspective is also included, to set milestones and define further steps until the next meeting.

4.2 Company RM context

From RM process perspective, they mostly focus on risk identification and on immediate determination of risk treatment strategies. It starts with usage of procedure for hazard identification, risk assessment and operation control which is included in the project definition phase. Continuous updating of risk lists during a project serves as a clear evidence of their understanding of RM iterative and repetitive nature. Although interviewees claim that often there is no need for detailed risk analysis and evaluation, in certain projects they are performing risk analysis in a classical sense and for that, they use methods like FMEA and risk matrix. The risk analysis methods enable them to shorten various risk lists and help them prioritize on the crucial ones. In addition, they are thoroughly discussing possible risk and failure propagation scenarios during project meetings. Clear trace of Lessons Learned on organizational level can be found, and controlling documents support re-usage of data and creation of RM formal documentation.

On organization level, many other procedures are prescribed for corrective and preventive actions, as well as for crisis management and dealing with unanticipated situations. This extended view and understanding of uncertainties, effects, risks and crisis definitely indicates awareness and consciousness of RM issues. Employees, which are responsible for managing projects had some training and education on RM practices and their purpose (usually some kind of PM certificate).

Since company belongs to specific industrial sector, huge demand for risk management within the company strategy is perfectly clear and understandable. Some aspects of RM are a legal requirement for this organisation, and therefore they are obliged to have RM practices implemented at least in some perspectives of their business.

Whole case company infrastructure, with predefined guidelines and procedures for various aspects and parts of product development process, and employees with sufficient knowledge enable usage of RM practices. Prescribed PD, PM, RM practices are used and modified in accordance with the context and needs of upcoming projects. Company mostly has characteristics of the Level 3 of RMM model, representing positive and successful example of risk management approach in practice. However, maturity level is not 4, since it would imply risk-based organization processes and risk ideas implemented to all activities.

4.3 Approach validation

Although company already reached high level of RMM, they are still trying to implement some new RM strategies and try to increase their knowledge level. For the time being, procedures are not including some of enumerated PD and RM methods. One of the reasons is the existence of huge gap between theory and practice in risk management (RM) for product development (PD) [Oehmen et al. 2010], [Hall 2011]. Often, methods and tools which can be found in literature were not properly tested and validated resulting in their low acceptance by industry practitioners. However, proposed approach can be found as quite useful highlighting them various possibilities and options for tailoring their RM approach. As part of this preliminary research, proposed support was presented and discussed with the employees (different roles in their design teams) to extend their view on RM issues and to modify their existing risk management approach.

Proposed approach could contribute to the suitability and effectiveness of the RM process within dynamic PD environment pointing out blind spots of their existing approach, but also providing recommendations about RM method selection. For example, certain risk analysis methods could help them to deepen the understanding of the possible design issues and facilitate their search for better technical and project solutions. Therefore, based on interviews and discussions, decisions about

application of new risk analysis methods were made (after testing period, results will be reported). Consequently, considering present RM practices within company, improvement is justified in adoption and application of new RM techniques. Employees claimed that such approach can be especially useful for companies in the earlier phases of RM implementation (and project management in general) which need more guidance in order to appropriately tailor their RM process. For the further validation and extension of existing approach, number of studied companies has to be increased.

5. Conclusions

The presented approach offers comprehensive view of the risk management, bridging different approaches which can be used for coping with risk issues within the product development environment. By linking Risk Management Maturity concept to product development, project management and risk management approaches (found in literature), improvement of the approach selection and modification is expected. Existing RMM model is extended by assigning these approaches and methods to particular maturity levels. Prescriptive character of proposed approach facilitates tailoring of overall RM approach and presents other options for improving the existing one. Despite the fact that validation process is still ongoing, preliminary results showed promising usefulness and purposefulness of our proposed approach. Of course, proposed approach requires further detailing to make it more applicable. Within included selection methods and recommendations, drawbacks were recognized (such as not sufficiently defined criteria or not appropriately assigned maturity levels) and therefore their adaptation and adjustment is also required.
Further research will include identification of other criteria for selection of appropriate RM approach (beside RM maturity) to better define given product development environment. Of course, since this is still early phase of the research, it will be continued in order to finally develop a framework for RM method selection which is needed. One of the possible directions of our research is evaluation and integration of software RM tools which can be used for particular RM methods.

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